Department for Business, Energy & Industrial Strategy

Advanced Gasification Technologies - Review and Benchmarking

Summary report

BEIS Research Paper Number 2021/038

Prepared for BEIS by AECOM & Fichtner Consulting Engineers

October 2021

Document approval

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Document revision record

Revision no	Date	Details of revisions	Prepared by	Checked by
P1	16/06/2021	Draft for Client Review	David Menmuir	Andy Cross
P2	14/07/2021	Client comments incorporated	David Menmuir	Andy Cross

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Acknowledgments

This study has been undertaken by AECOM Limited and Fichtner Consulting Engineers Limited. The main contributors were:

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We would like to thank the Project Steering Board for their extensive contributions and support during this review:

- Adrian Judge, Tolvik Consulting
- Geraint Evans, BeaconTech Limited
- Hamish McPherson, Bioenergy Infrastructure Group
- Hilary Stone, Renewable Energy Association
- Patricia Thornley, Aston University
- Peter Coleman, BEIS
- Stephen Ray, Macquarie Capital
- Tom Reid, Department for Transport

In addition, we have received valuable information from the following technology developers:

- Advanced Biofuel Solutions Limited (ABSL)
- Kew Technology Limited
- LanzaTech Incorporated
- PowerHouse Energy Group

- Valmet
- Velocys

The views expressed in this report are those of the authors and do not necessarily reflect those of the Steering Board or technology suppliers.

1 Introduction

AECOM and Fichtner Consulting Engineers have undertaken a study to investigate the current techno-economics of advanced biomass and waste gasification technologies for the generation of energy products on behalf of the Department for Business, Energy and Industrial Strategy (BEIS). The term advanced gasification technologies (AGTs) is used to refer to thermal conversion technologies (gasification or pyrolysis) for conversion of biomass or waste into aviation fuel, diesel, hydrogen, methane and other hydrocarbons. This study does not include technologies used to produce electricity.

Some configurations of AGTs have the potential to produce hydrogen and hydrocarbon products with lower associated emissions of carbon dioxide (CO_2) than conventional means of production. Furthermore, with the addition of carbon capture and storage (CCS) technologies there is an opportunity to operate with a net negative release of CO_2. A proportion of the CO_2 generated during the conversion process is discharged as a relatively pure stream and this is a significant advantage in relation to the addition of CO_2 capture technologies. However, AGTs have not yet reached commercialisation.

Most gasification projects in the UK have aimed to produce electricity with limited success. The subsidy regimes available in the UK to date have promoted the generation of electricity rather than fuel or chemical production.

The purpose of the study was to assist BEIS in understanding the current development status of AGTs and to inform future policy direction and innovation spending in relation to this class of technologies. The study was split into tasks as described below.

- Task 1 – Project Set-up and Steering Board Formation
- Task 2 – Assessment of Current Status of Advanced Gasification Technologies
- Task 3 – Techno-economic Assessment Methodology and Product Cost Benchmarking
- Task 4 – Opportunities and Barriers
- Task 5 – Techno-economic Analysis

This report contains an overview of the key outputs from the tasks conducted and provides opinions on the next steps that could be taken in the development of AGT technologies.

2 Current Status of AGTs

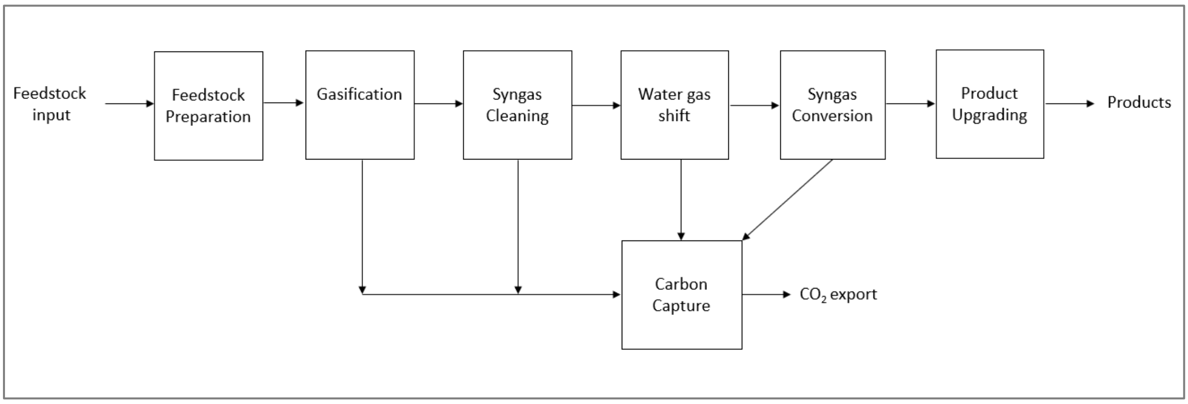
2.1 AGT Configuration

A generic block flow diagram for an AGT is presented in Figure 1 below. AGTs typically consist of the following key component systems:

1. feedstock preparation;
2. feedstock storage and transport;
3. a gasification or pyrolysis reactor;
4. syngas cleaning;
5. syngas reforming; and
6. a syngas/pyrolysis oil upgrading system.

Carbon capture may be added to reduce the CO_2 emissions associated with the products generated.

Figure 1. Generic AGT Block Flow Diagram



The AGTs under consideration in this study are fuelled by either biomass or waste. A wide variety of different wastes or biomasses could be processed. In general, biomass is a technically simpler fuel to process but has a higher associated cost. There would usually be a revenue associated with the use of waste as a feedstock. For all technologies considered, pre-treatment of the feedstock is required to meet the technical specifications of the gasification process.

A range of biomass feedstocks and waste compositions were considered at the early stages of this study. For the techno-economic assessments a single municipal solid waste (MSW) specification and two biomass specifications were assumed, as presented in Table 1 below.

Table 1 Typical feedstock properties for design basis

Parameter	Unit	Wood Chip	Wood pellets	MSW
Carbon	% ar	25.50	47.43	26.30
Hydrogen	% ar	3.15	5.86	3.69
Nitrogen	% ar	0.15	0.28	0.77
Oxygen	% ar	20.89	38.85	15.64
Sulphur	% ar	0.01	0.02	0.13
Chlorine	% ar	0.01	0.01	0.96
Ash	% ar	0.30	0.56	17.86
Moisture	% ar	50.00	7.00	34.65
Net Calorific Value (NCV)	MJ/kg	8.14	17.24	9.70

2.1.2 Gasification

The technologies reviewed are based on fluidised bed gasification technologies. This technology has been adopted for the purposes of this study because the majority of AGTs under development use fluidised bed gasifiers for similar applications to those considered. At the scale of plant considered and based on the required output for commercial operation, entrained flow gasifiers are the only other type of gasifier with a thermal capacity in excess of 100 MW (on a net calorific value (NCV) basis) per stream. A change in the type of gasifier reactor used would not alter the requirement for feedstock preparation upstream of the gasifier and syngas treatment and upgrading downstream of the gasifier.

2.1.3 Syngas Cleaning

The syngas generated in the gasifier will contain tars, particulates and other contaminants. Multicomponent syngas clean-up systems are required to reliably produce a syngas of acceptable quality for subsequent use in the syngas upgrading systems.

2.1.4 Syngas Upgrading

Upgrading of syngas from biomass and waste derived feedstocks requires similar equipment to that used in the gasification of petroleum-based feedstocks or coal. This will involve water-gas shift reactors for adjusting the H_2 to CO ratio and Fischer-Tropsch (FT) reactors or other reaction processes for producing longer chain hydrocarbon molecules. New types of FT reactor systems and higher activity catalysts are being developed for the upgrading of syngas from biomass and waste derived feedstocks.

Some of the technologies under development have a full chain system from feedstock through to syngas upgrading, whereas other technologies have coupled a third-party syngas production system to a newly developed syngas upgrading system.

2.1.5 Pyrolysis

Many pyrolysis systems are small scale modular plants with feedstock throughput capacities ranging from 7,000 – 10,000 tonnes per annum (tpa). These systems are suited to the conversion of niche waste streams, or the production of niche fuels, rather than large scale production. This study focussed on larger scale projects, so pyrolysis technologies were not considered for the techno-economic analysis.

2.2 Development Status of AGTs

As outlined in the Task 2 report, none of the AGT technologies reviewed are in commercial operation. For most of the systems investigated, parts of the process have been tested but the complete system has not been integrated and demonstrated at commercial scale. Where all components have been integrated, these plants are being operated as demonstrators with the aim of validating predicted plant performance. For the technologies reviewed the Technology Readiness Levels (TRLs) range from 6-8.

Several pyrolysis systems are in commercial operation, but these are small modular plants which do not have the capacity for large scale production.

The AGTs in development for the production of liquid drop-in fuels have the potential to be scaled-up to produce large volumes of fuel. The technologies reviewed, with associated feedstocks and products, are listed in Table 2 below.

Table 2: Advanced Gasification Technologies Reviewed

Technology	Feedstock in current use	Process plant	Product	Technology readiness level
Advanced Biofuel Solutions Limited	RDF	Fluidised bed gasifier	Bio Synthetic natural gas (BioSNG)	6
Enerkem Incorporated	RDF	Fluidised bed gasifier	Methanol and ethanol	8
GoBiGas	Biomass	Fluidised bed gasifier	Methane	8
Kew Technology	Densified RDF	Fluidised bed gasifier	Electricity, H_2 and liquid fuel	6
PowerHouse Energy Group	RDF, SRF, and mixed plastics	Rotary kiln gasifier	Electricity and H_2	6
Sumitomo Foster Wheeler	Biomass	Fluidised bed gasifier	Renewable diesel	7
ThermoChem Recovery International	RDF	Fluidised bed gasifier	Syngas for aviation fuel and diesel	7
Alphaco	Tyres	Pyrolyser	Pyrolysis oil	9
ReOil	Tyres	Pyrolyser	Pyrolysis oil	9
Standard Gas	RDF	Pyrolyser	Electricity and methane	5/6
Velocys	Syngas	Fischer-Tropsch	Renewable diesel and aviation fuel	8
LanzaTech	Syngas and waste gases	Fermentation process to convert syngas	Ethanol, aviation fuel	9

3 Opportunities and Barriers

3.1 UK Gasification Experience

In the last 20 years, more than 30 gasification projects using waste or biomass have been developed in the UK with assistance from a variety of government support mechanisms. All these projects were intended to produce electricity. However, many of these projects were never successfully commissioned, did not perform in line with initial expectations or only operated for a limited period. The performance issues experienced by waste and biomass fired gasification projects intended to generate electricity must be considered in relation to assessing the performance risk associated with the development of more technically complex AGTs. Details of UK gasification experience are provided in tasks 2 and 4.

3.2 Lessons Learned

Projects often failed to meet initial expectations for a combination of economic, technical and non-technical reasons. Key lessons for the development of future gasification projects include:

1. Incentive schemes should only support technologies that have demonstrable advantages over existing technologies. For example, a net reduction in CO_2 emissions.
2. Realistic assessments of cost and performance risk (particularly availability) are required.
3. Commercial pressures on projects using new technologies can lead to a lack of robustness in plant design and insufficient allowances for plant optimisation.
4. Contractor competency in relation to the delivery of complex process plant is required.
5. The impact of feedstock quality and variability needs to be understood.
6. The complexities of significant scale-up of process equipment needs to be understood.

3.3 Opportunities and Barriers

The primary opportunity for AGTs is as a means of producing low carbon hydrogen and hydrocarbon products. The addition of carbon capture technology would give AGTs the potential to operate with a net negative release of CO_2. Products from different AGT configurations will have different associated net CO_2 emissions. Understanding the net CO_2 emissions of products from AGTs relative to existing sources of the products is key to assessment of their value and potential future role.

Potential barriers to deployment of AGTs include:

1. **Plant Availability** - The ability to achieve an acceptable balance between equipment cost and plant availability remains to be proven.
2. **Marginal abatement cost of CO_2** - There may be simpler, lower cost options for reducing emissions from sectors of the economy that could use the products from AGTs.
3. **Requirement for CCUS** - Some AGT configurations may require CCUS infrastructure to provide CO_2 emission reductions and the infrastructure to support this is currently unavailable.
4. **Feedstock Supply** – Sustainable biomass and residual waste are limited resources with other competing uses. Feedstock supply limits the overall decarbonisation potential of AGTs.
5. **Overall Conversion Efficiency** – The conversion of variable feedstocks into consistently high-quality products is a complex multi-stage conversion process requiring auxiliary inputs. A low overall conversion efficiency, including auxiliary energy and chemical inputs, may create a challenge in relation to competition with other conversion processes.

4 Techno-economic Analysis

4.1 Methodology Overview

Twenty (20) AGT configurations were evaluated using different combinations of product, scale and feedstock. Table 3 shows these configurations and the annual mass of product generated based on the product yields provided by equipment suppliers. Details of the assessment methodology and underlying assumptions used are presented in the Task 3 and Task 5 reports.

Table 3. AGT configurations and product outputs

Parameter	Small Biomass (330,000 tpa, woodchips)	Large Biomass (1M tpa, pellets)	Small waste (100,000 tpa)	Large waste (550,000 tpa)
Hydrogen (tpa)	12,600	72,600	3,900	22,000
Methane (tpa)	30,300	175,200	9,800	55,100
Aviation Fuel (SPK, tpa)	21,300	126,100	6,200	36,300
FT diesel (tpa)	23,000	135,900	6,800	39,200
Methanol (tpa)	91,000	523,200	28,200	158,700

The rationale behind the plant sizes selected was as follows.

- **Small scale biomass**, sized at 330,000 tpa of woodchips, is equivalent to a gasifier thermal capacity of 100 MW_{th} (NCV basis). This is a similar size to the larger biomass plants in the UK fired by wood chip or straw sourced in the UK which generate electricity.
- **Large scale biomass**, sized at 1m tpa of imported wood pellets, is equivalent to a gasifier thermal capacity of 643 MW_{th} (NCV basis). This size of plant has been included to demonstrate the potential impact of economies of scale. It is larger than could feasibly be expected to attract investment at present. However, it is smaller than the UK's largest biomass plants, with coal conversion plants at Drax and Lynemouth consuming about 5 Mt of wood pellets annually.
- **Small scale MSW**, sized at 100,000 tpa of MSW, is equivalent to a gasifier thermal capacity of about 36 MW_{th} (NCV basis). Such a plant is at the smaller end of the range of UK energy from waste plants. However, it is large enough to be a significant step on the way to proving the technology and developing larger plants. It is also possible that 100,000 tpa is a sensible option for regions with lower waste arisings.
- **Large scale MSW**, sized at about 550,000 tpa of MSW, is equivalent to a gasifier thermal capacity of 199 MW_{th} (NCV basis). At the current status of development this would be a multi-stream plant. This is slightly larger than the larger AGT plants currently proposed internationally but is much smaller than the UK's larger energy from waste plants. The Runcorn plant processes almost 1 Mtpa of RDF for generation of heat and

power. It will therefore benefit from economies of scale but is still expected to be a manageable size to source waste.

Capital costs for first of a kind (FOAK) plants were estimated using supplier information combined with internal data available to Fichtner and AECOM. Systems such as on-site power generation and oxygen separation, which could benefit plant economics but increase plant complexity, were not included in the modelling. Results are presented in Table 4.

Table 4. AGT configuration total capital cost estimations, 2025 basis

	Small Biomass (330,000 tpa, woodchips)	Large Biomass (1M tpa, pellets)	Small waste (100,000 tpa)	Large waste (550,000 tpa)
Hydrogen	£304m	£982m	£171m	£499m
Methane	£293m	£946m	£164m	£481m
Aviation Fuel (Synthetic paraffinic kerosene)	£346m	£1,110m	£193m	£562m
Fischer-Tropsch diesel	£346m	£1,110m	£193m	£562m
Methanol	£320m	£1,031m	£179m	£523m

The current developmental status of AGTs and lack of plants operating at the scales under consideration in this study limits the availability of cost information data and creates uncertainty in the cost estimations. A sensitivity analysis has been conducted to demonstrate the impact of varying capital costs on product costs.

Operating costs were built up from a combination of supplier information, data from the mass balance models on consumables and residues and experience from similar waste and biomass processes.

The data gathered was used in techno-economic models to predict levelised costs for each product. The models also assessed the impact of adding carbon capture on the levelised cost of the products.

4.2 Results

The levelised cost of product results obtained have been compared with the cost of fossil resource derived products and products produced by other means such as electrolysis derived hydrogen or methane from anaerobic digestion. A summary of these results is presented in Table 5.

Table 5. AGT levelised cost of products

Parameter	Small Biomass (330,000 tpa, woodchips)	Large Biomass (1M tpa, pellets)	Small waste (100,000 tpa)	Large waste (550,000 tpa)	Counterfactual	Counterfactual representative cost and cost range
Hydrogen (£/kg)	£7.99	£6.50	£7.53	£3.52	SMR SMR with CCS Electrolysis	£1.20 (£0.60-£1.50) £1.70 (£1.00 – £2.20) £6.00 (£2.40 - £13.30)
Methane (£/kg)	£3.26	£2.66	£2.90	£1.35	Natural Gas Landfill methane AD	£0.28 (£0.19 - £0.42) £0.65 (£0.65-£0.75) £1.10 (£0.70 - £1.70)
Aviation Fuel (SPK, £/kg)	£4.97	£3.83	£5.21	£2.33	Fossil derived	£0.49 (£0.32 - £0.76)
FT Diesel (£/kg)	£4.61	£3.56	£4.82	£2.17	Fossil derived	£0.65 (£0.51 - £0.83)
Methanol (£/kg)	£1.15	£0.93	£1.11	£0.53	Fossil derived	£0.32 (£0.16 - £0.42)

- Details of the assumptions made in relation to the above results and the sources for the counterfactual product costs are provided in the Task 5 report.
- In all cases, the levelised costs of products (LCOX) from AGTs are higher than when the equivalent product is derived from fossil resources. The results indicated that the cost of the products generated were between two and ten times more expensive than the fossil origin alternatives. The lowest cost products were obtained from the large-scale waste options and the highest cost of products were from the small- scale biomass plants. The large-scale waste plants benefited from both economies of scale and revenue from accepting the waste feedstock.

As would be expected, adding carbon capture equipment increases the LCOX of the products when a zero cost of emitting CO_2 to the atmosphere is assumed. For AGT configurations that provide a CO_2 saving relative to the counterfactual product or can operate as CO_2 negative processes with the addition of carbon capture, usage and storage (CCUS), then the difference in the cost of production will be reduced if the cost of emitting CO_2 to the atmosphere increases. The production of a relatively pure stream of CO_2 by the AGT processes is an advantage in relation to the addition of carbon capture equipment.

Table 6 shows the LCOX when CO_2 from the concentrated CO_2 stream is captured; the mass of CO_2 available in this stream is also shown. Capturing CO_2 only from the concentrated stream allows most of the CO_2 released from the process to be captured and has a lower cost than capturing all CO_2 from the process. Further cost details of the CO_2 capturing process and the impact of also capturing CO_2 from the flue gas is presented in the Task 5 report.

Table 6. Impact of CCS on levelised cost of products

Parameter	Small Biomass (330,000 tpa, woodchips)	Large Biomass (1M tpa, pellets)	Small waste (100,000 tpa)	Large waste (550,000 tpa)
Hydrogen				
CO_2 to atmosphere	55,000	288,000	17,000	87,000
CO_2 in rich stream	248,000	1,425,000	76,900	432,000
Product cost (£/kg)	£8.21	£6.76	£7.79	£3.81
Methane				
CO_2 to atmosphere	47,000	241,000	14,000	68,000
CO_2 in rich stream	184,500	1,048,200	57,100	317,700
Product cost (£/kg)	£3.33	£2.74	£2.99	£1.44
Aviation Fuel (Synthetic paraffinic kerosene)				
CO_2 to atmosphere	72,000	394,000	23,000	123,000
CO_2 in rich stream	151,800	854,600	47,000	259,300
Product cost (£/kg)	£5.50	£3.92	£5.32	£2.44
Fischer-Tropsch diesel				
CO_2 to atmosphere	69,000	377,000	22,000	118,000
CO_2 in rich stream	151,700	854,200	47,000	259,100
Product cost (£/kg)	£4.69	£3.65	£4.93	£2.27
Methanol				
CO_2 to atmosphere	29,000	140,000	9,000	42,000
CO_2 in rich stream	156,200	889,500	48,300	269,700
Product cost (£/kg)	£1.17	£0.95	£1.14	£0.56

The costs derived for the configurations with carbon capture and storage do not include a cost for export of the CO_2 collected or connection to CO_2 transport and storage infrastructure.

One of the main risks associated with AGTs is the ability to achieve high availability operation without incurring excessive capital and operating costs. Whilst a target plant availability of 85% from the first year of operation has been assumed for the purposes of deriving the levelised costs of products, this should not be considered as the expected availability for a FOAK plant for the configurations presented. The risk associated with the assumed performance of the AGTs must be considered in drawing conclusions from, or conducting further work, based on the results presented.

4.3 Second Generation AGTs

- Any new AGTs should be built in a robust manner to maximise availability. Furthermore, the complexity of initial projects should be minimised where possible, even if this means initial product costs are higher due to lower yields or increased consumables costs.
- For AGTs, we consider that reductions in product cost as the technology matures and number of plants deployed increases are more likely to be achieved by increasing yields or reducing consumables costs. For some AGTs, electricity could be generated on site using waste heat from the process.
- The yield of the hydrocarbon products (transport fuels, methane or methanol) could be significantly increased by using imported H_2 to provide the optimum H_2 to CO ratio for synthesis of the products. This relies on the availability of H_2 at a suitable cost and with acceptable associated CO_2 emissions.

5 Development Pathway

The results of this study contribute to understanding the potential value of developing AGTs in the UK. This study can be used in conjunction with other information to better understand the future role of AGTs, what configurations are most valuable, how best to promote development and lessons to be learned from the historical development of gasification technology.

5.1 Future Role of AGTs

Factors to consider in relation to the potential future role of AGTs in the UK energy system include.

1. **Which products to manufacture –** The LCOX values provided can inform decisions on which products should be targeted. In addition, decisions on product selection will be influenced by other technological and policy options available for controlling CO_2 emissions in the sectors of the economy where the products will be used.
2. **Potential overall scale of deployment** – The volume of product that can be generated from AGTs is limited by the mass of feedstock available, and there are competing uses for the feedstocks used. Further work could be conducted to quantify the likely mass of feedstock that could be available to AGTs, including consideration of the most likely sources of competition for this material.
3. **Timescale for deployment** – Information provided on the current status of AGTs and the barriers to their development can be used to predict a likely timescale for deployment. The current status of the technologies varies between the products under consideration. An example deployment pathway based on the development of a 100,000 tpa plant has been presented.
4. **Marginal abatement cost of CO_2 –** The marginal abatement cost of CO_2 influences the potential value of AGTs as a means of controlling CO_2 emissions. Information supplied can be used in a whole life CO_2 assessment for hydrocarbon products from AGTs and in the calculation of the marginal abatement cost of CO_2.

Whilst there is a need to conduct further work in relation to the factors listed above, it must be recognised that they are complex there will unavoidably be a significant degree of uncertainty in results obtained.

5.2 Project Development

If the development of AGTs is to be continued, to realise their potential to be used as a part of the future net-zero energy system, then the pathway towards deployment of commercial facilities should be considered. Factors to consider relating to the development of new facilities are outlined below.

The government's role in the development of new projects could be as the project owner or be based around assessment of projects being developed by third parties and working with these organisations to provide appropriate support if robust justification for the support can be provided.

1. **Detailed Technology Assessment -** This study provided an overview of the development status of AGTs. If support is to be provided to a specific project, then detailed due diligence of the proposed technology should be conducted. Such an assessment could review evidence of the performance claims made by suppliers and consider the risks associated with predicted improvements or any proposed alterations to the equipment.

2. **Financial Support Mechanisms -** Many of the technologies considered have not yet demonstrated a level of performance where an incentive based on product output would be an appropriate support mechanism. Premature exposure to a fully commercial environment using output-based incentives has historically led to issues in the development of gasification technology.

   For these earlier stage technologies, development priorities would be the demonstration of reasonable performance at a smaller scale prior to scaling up or full exposure to a more commercial environment. This type of earlier stage development, where reliable operation may not be expected, may be best supported through a grant funding type approach.

3. **Project Scale –** The most appropriate scale for a new project will depend on a variety of factors including the scale, performance, configuration and feedstock used at any reference facilities. It is important that the complexities of technology scale-up are understood and that challenges are not underestimated.

4. **Project Scope –** Innovation support could either be provided to full chain projects, that include all equipment from feedstock reception to final product manufacture, or to development projects that focus on demonstration / improvement of individual components or subsystems that would form part of an AGT. There could be opportunities for valuable innovation across the whole AGT process. Notable areas identified for innovation include:

   a) Feedstock processing and gasifier design improvements to improve availability.

   b) Syngas clean-up equipment to effectively control contaminant concentrations to within the specifications required for downstream equipment.

   c) Syngas upgrading equipment for the manufacture of different products.

   d) Process integration at a commercial scale.

For each of these areas, innovation would seek to improve factors including reliability of equipment, conversion efficiency, yield, maintenance requirements and cost of equipment.

5.3 Example Development Pathway

In Task 5, a development pathway was proposed based on demonstrating the production of products from MSW at a scale of 100,000 tpa. Whilst MSW is a more technically challenging fuel than biomass, if reliable operation can be achieved it brings potential economic advantages due to feedstock gate fee. A plant size of 100,000 tpa is large enough to demonstrate the performance of the technology at a commercial scale and to allow scale-up to larger commercial plant sizes, without the need for excessive scale-up factors. A switch to biomass fuel may be possible without major alterations if the high cost of biomass can be overcome. Task 5 indicated that costs for this scale of plant, without CCS, could be in the region of £160 - £200m depending on the proposed product.

This pathway predicted that, following selection of the most appropriate technology and support mechanism, a 100,000 tpa FOAK project could be developed leading to a construction phase between 2023 and 2026. If the plant were to perform well, this would demonstrate the technology and provide confidence to allow further projects to be developed from 2030. This pathway relies on the existence of a suitably developed technology that is ready to be deployed at 100,000 tpa scale. The availability of such a technology would need to be confirmed through detailed technology assessment.

For many of the technologies under consideration in this study a smaller demonstration project may be more appropriate. To promote efficient development of AGT technology, and allow potential benefits to be realised, the scale of any future demonstration projects should consider the size and performance of existing reference facilities. Selection of an appropriate plant scale will help to mitigate technical issues relating to scale-up and capex exposure, and ultimately lead to faster and more efficient deployment of the technology.

If a demonstration plant is to be supported using innovation funding, consideration should be given to allowing a stream of syngas to be diverted to different syngas cleaning and upgrading technologies. This arrangement could take advantage of the fact that the front-end processing equipment of different AGT plants operating on the same feedstock can be similar. A plant of this kind could allow a range of syngas upgrading technologies to be developed without having to construct multiple demonstration projects. This could promote faster and lower cost development of syngas processing and upgrading technologies.

Abbreviations

AD	**Anaerobic Digestion**
AGT	Advanced Gasification Technology
BEIS	Department for Business, Energy & Industrial Strategy
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation and Storage
CO_2	Carbon Dioxide
FOAK	First of a Kind
FT	Fischer-Tropsch
H_2	Hydrogen
MSW	Municipal Solid Waste
RDF	Refuse Derived Fuel
SRF	Solid Recovered Fuel
TPA	Tonnes Per Annum
MTPA	Million Tonnes Per Annum
MW_{th}	Mega Watts Thermal
SMR	Steam Methane Reforming
SPK	Synthetic Paraffinic Kerosene
TRL	Technology Readiness Level

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